An Evidence Based Search Method for Neutron Star Ring-downs

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Neutron Star Ring-downs & Search Triggers

Neutron star non-radial quasi-normal oscillations lead to the emission of gravitational waves in the form of a decaying sinusoid or ring-down. There are a variety of mechanisms to excite these modes, including:

- Pulsar glitches occur when the superfluid interior of the neutron star suddenly decouples from the crust. The glitch is observed as a sudden discontinuity in the pulsar spin-down rate
- Soft γ-ray repeater flares are the result of massive magnetic field reconfiguration in highly magnetised neutron stars known as magnetars. Here, the event is observed as a massive release of γ-rays.

Bayesian Model Selection

We apply Bayesian model selection to the robust detection of neutron star ring-downs by defining the following models:

- M_1: the data, denoted D, consists of a gravitational wave ring-down and Gaussian white noise.
- M_2: the data contains consists of only Gaussian white noise.
- M_3: the data contains an instrumental glitch in the form of a sine-Gaussian, plus Gaussian white noise.

Compare the probability that the data contains a ring-down with the probability that it contains noise *or* an instrumental glitch through the odds ratio:

$$O_{1,23} = \frac{p(D|M_1)}{p(D|M_2) + p(D|M_3)}$$

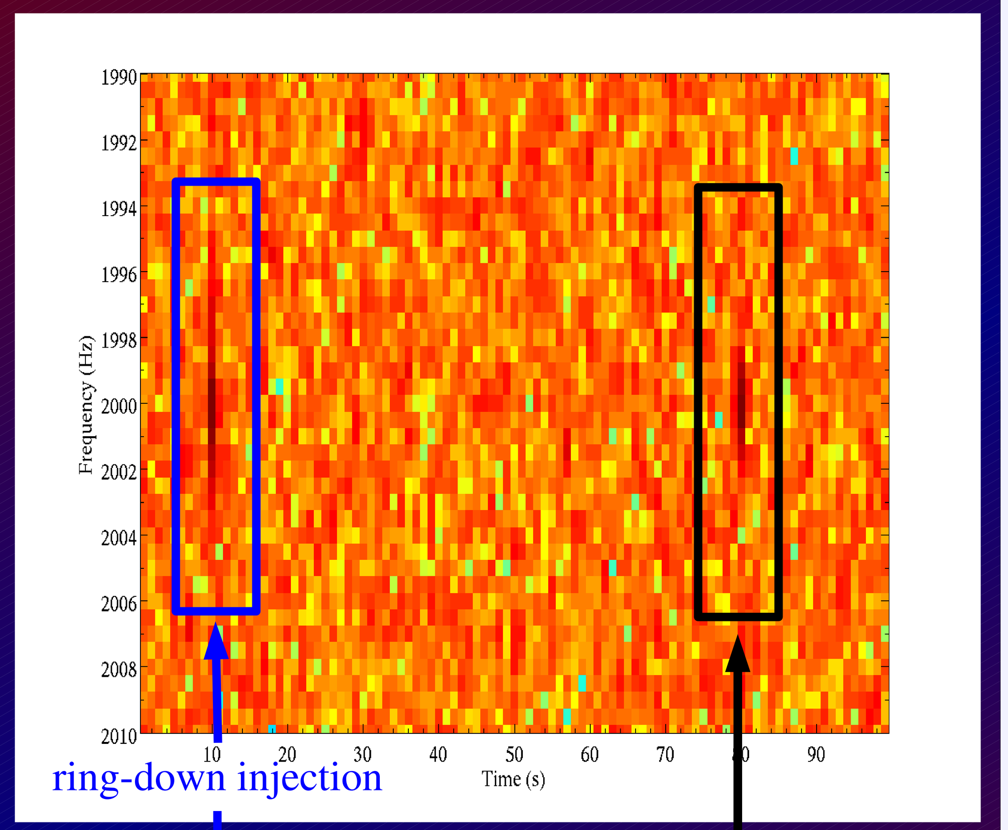
where $p(D|M_i)$ is the evidence for model M_i (i=1,2,3), defined as the likelihood marginalised over all model parameters θ_i:

$$p(D|M_i) = \int_{\theta_i} d\theta_i p(\theta_i|M_i) p(D|\theta_i, M_i)$$

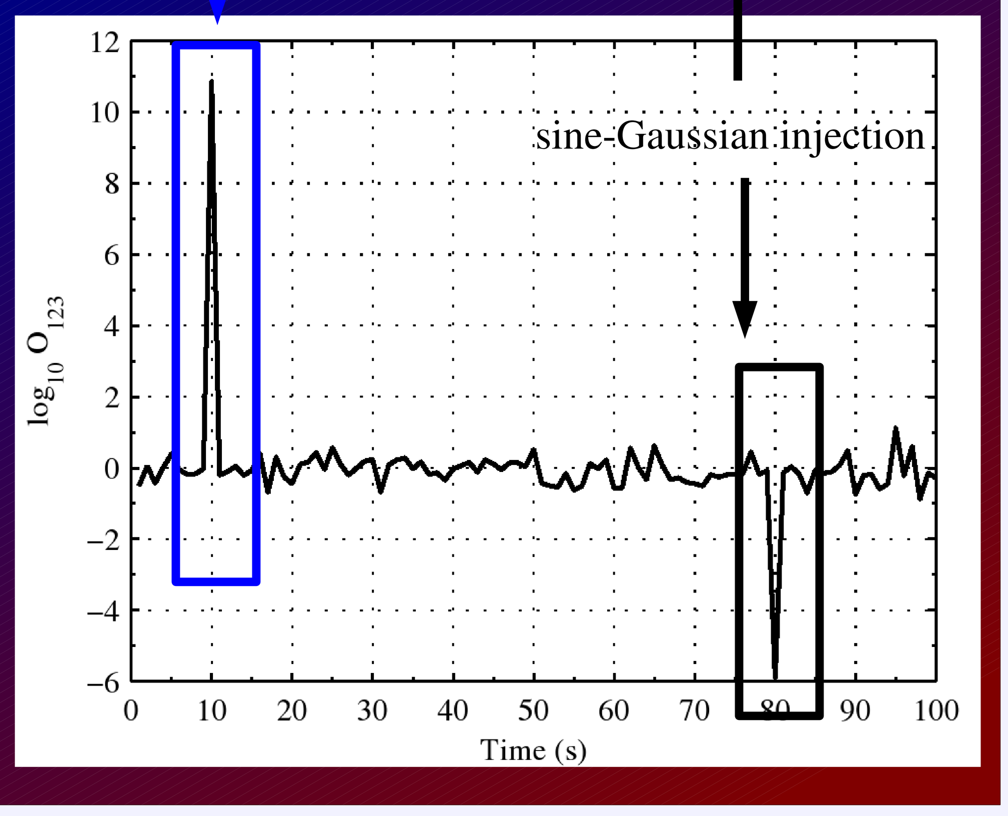
We find this method successfully detects our target waveform (the ring-down), while being robust against sine-Gaussian instrumental glitches. Performance is indicated by the receiver operating characteristic curves.

Demonstration

To demonstrate the operation of the algorithm, we compare the odds ratios obtained from a ring-down and a sine-Gaussian injected into synthetic Gaussian white noise.

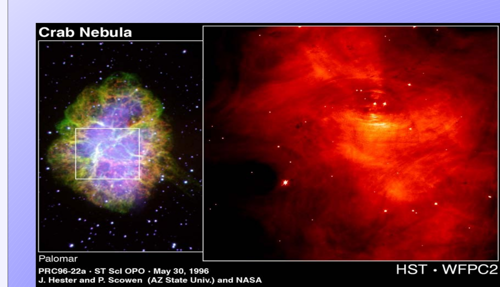


The spectrogram shows a typical ring-down waveform injected into synthetic noise at 10 seconds. A sine-Gaussian is injected at 80 seconds to simulate an instrumental glitch. Both signals have a signal-to-noise ratio ~ 20.



The output of the odds algorithm. The ring-down signal has been detected with odds much higher than the background. We also see that the much lower odds rule out the instrumental glitch as a gravitational wave signal.

Analysis Pipeline



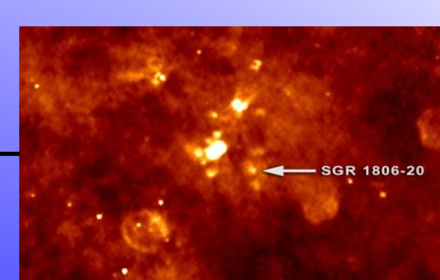
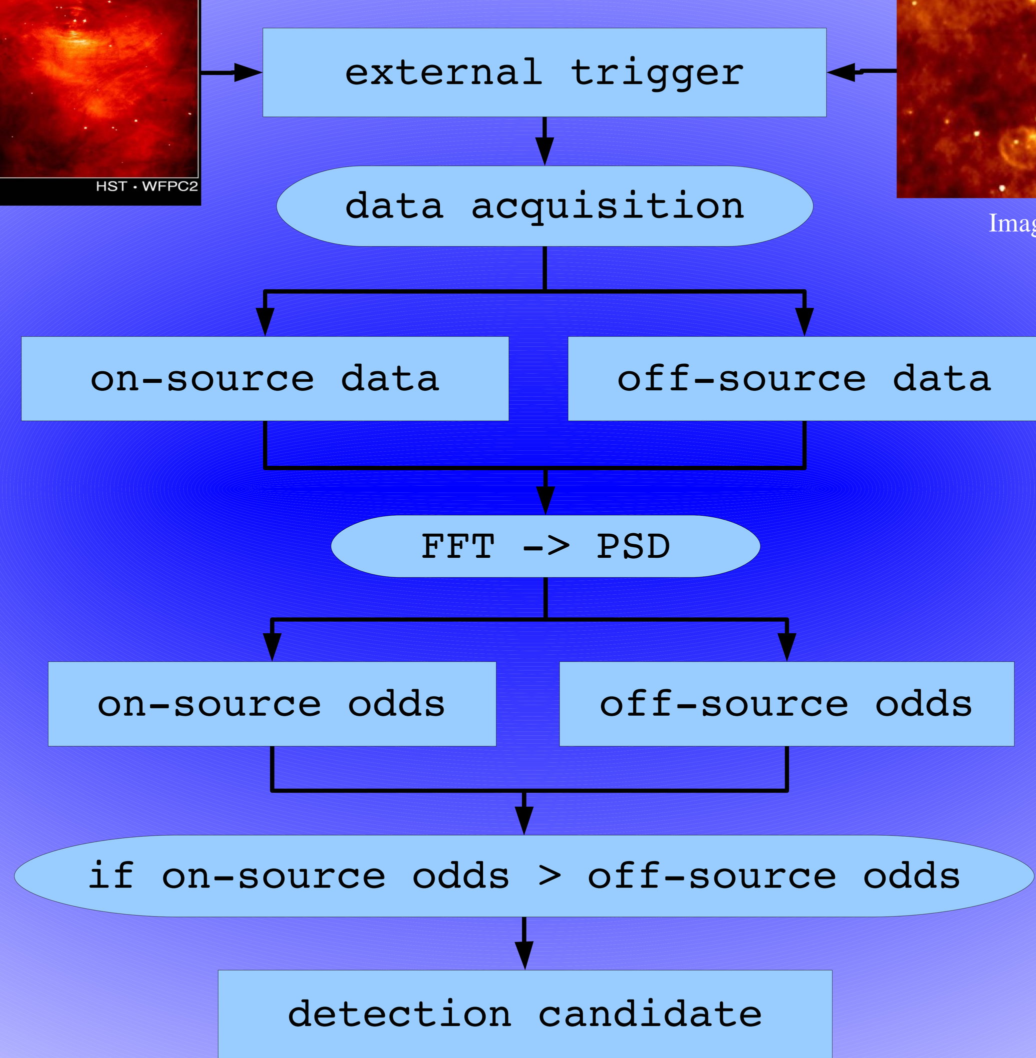
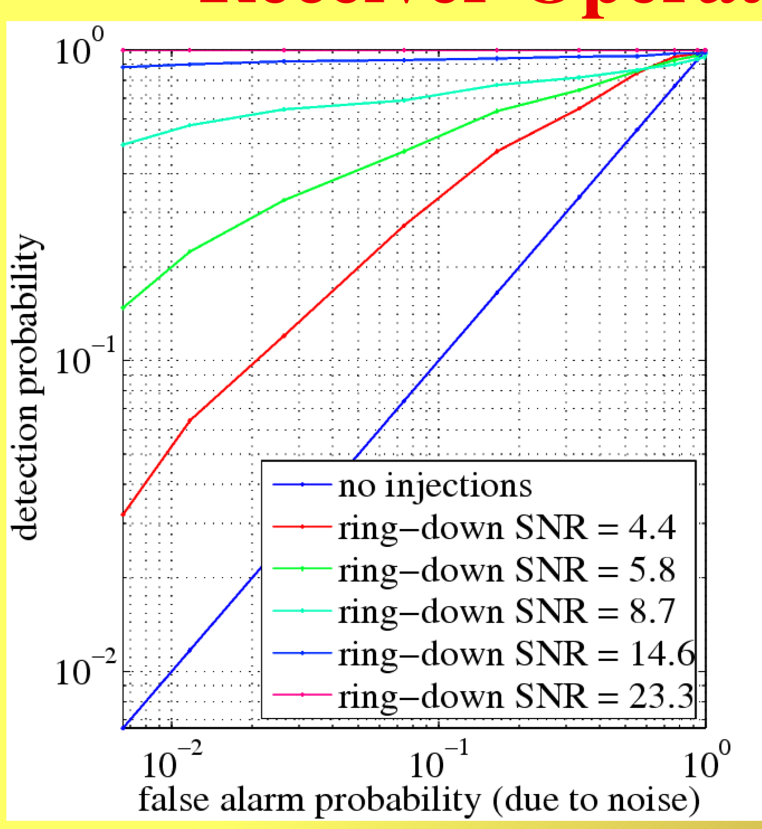
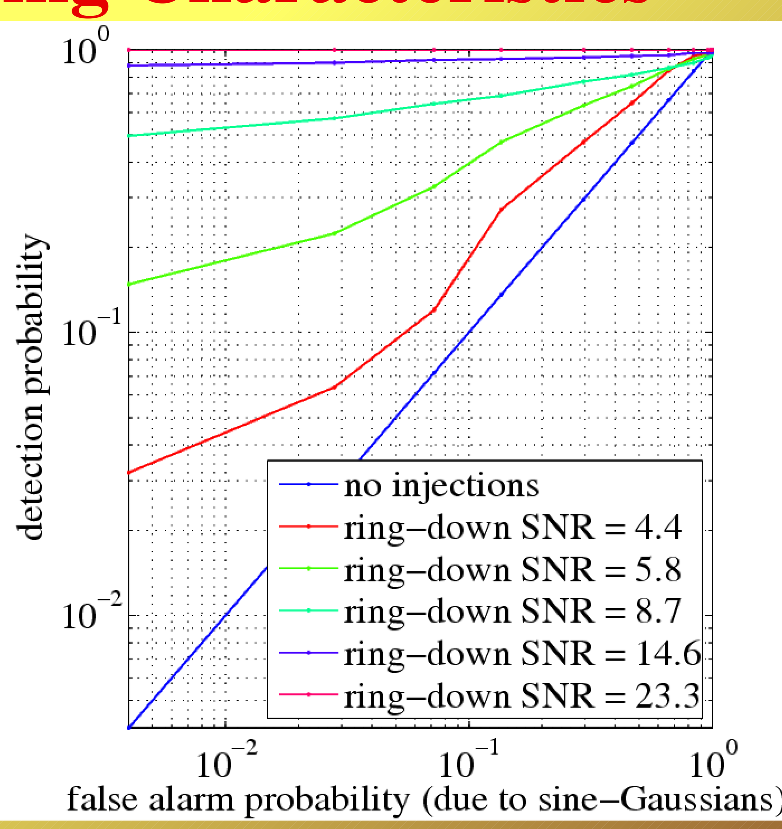


Image credit: University of Hawaii



Receiver Operating Characteristics





References

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